

AUTOMATION IN THE SPACE STATION MODULE POWER MANAGEMENT AND  
DISTRIBUTION BREADBOARD

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## ABSTRACT

The Space Station Module Power Management and Distribution (SSM/PMAD) Breadboard, located at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, models the power distribution within a Space Station Freedom Habitation or Laboratory module. Originally designed for 20 kHz ac power, the system is now being converted to high voltage dc power with power levels on a par with those expected for a space station module [1].\*

In addition to the power distribution hardware, the system includes computer control through a hierarchy of processes. The lowest level process consists of fast, simple (from a computing standpoint) switchgear, capable of quickly safing the system. The next level consists of local load center processors called Lowest Level Processors (LLP's). These LLP's execute load scheduling, perform redundant switching, and shed loads which use more than scheduled power. The level above the LLP's contains a Communication and Algorithmic Controller (CAC) which coordinates communications with the highest level. Finally, at this highest level, three cooperating Artificial Intelligence (AI) systems manage load prioritization, load scheduling, load shedding, and fault recovery and management. The system provides an excellent venue for developing and examining advanced automation techniques. This paper examines the current system and the plans for its future.

## INTRODUCTION

As the electrical power requirements for spacecraft have increased, the problems of managing these large systems have also increased. Since 1978, NASA/MSFC has been actively working the problem of spacecraft power system automation. This work has progressed from reference power system studies to operating test beds employing both conventional and expert system computer controls. One of these systems is the SSM/PMAD Breadboard [2].

\*Reference 1 is used throughout this paper unless otherwise noted.

## SYSTEM DESCRIPTION

The automation studies which lead to the SSM/PMAD Breadboard began at MSFC in 1984. A primary purpose of the breadboard is to investigate automation techniques appropriate to a large PMAD system such as will exist on Space Station Freedom. The current SSM/PMAD Breadboard consists of the 20 kHz power distribution hardware, the automation and control software, and the computer hardware shown in Figure 1.

## Power Distribution Hardware

A typical configuration of the breadboard is shown in Figure 1. The 20-kHz, 208-Vac, single-phase power is supplied to both of the Power Ring Buses by a 3-kW Mapham-type power supply. The distribution system contains three types of switches: the Remote Bus Isolators (RBI's), the Remote Controlled Circuit Breakers (RCCB's), and the Remote Power Controllers (RPC's). The loads include light bulbs (two 150 W bulbs in series for each of four loads), 12 resistive loads adjustable to 1250 W in 250-W increments, and several low-power LED's. Further, the components of a given type are interchangeable to allow testing of different system configurations. The shaded areas in Figure 1 denote sections of the system for which no hardware is yet available, but the following system components descriptions will assume full system capabilities.

The Ring Bus architecture allows hardware to be powered despite any failure of a single RBI, and permits a section or sections of components to be isolated from a powered bus by the RBI's. Each Ring Bus contains three 15-kW RBI's, shown as black diamonds in Figure 1. To avoid problems with current sharing and power flow, only two RBI's on a given Ring Bus may be closed at any given time. The RBI's are not designed to be opened while current is flowing through them.

The RCCB's are shown as square white boxes in Figure 1. Each RCCB contains a remotely controlled mechanical switch, rated at 10 kW, which will open automatically on an I<sup>2</sup>t condition. In addition, each RCCB contains current-sensing electronics which can report current levels, switch status, and control status on request.

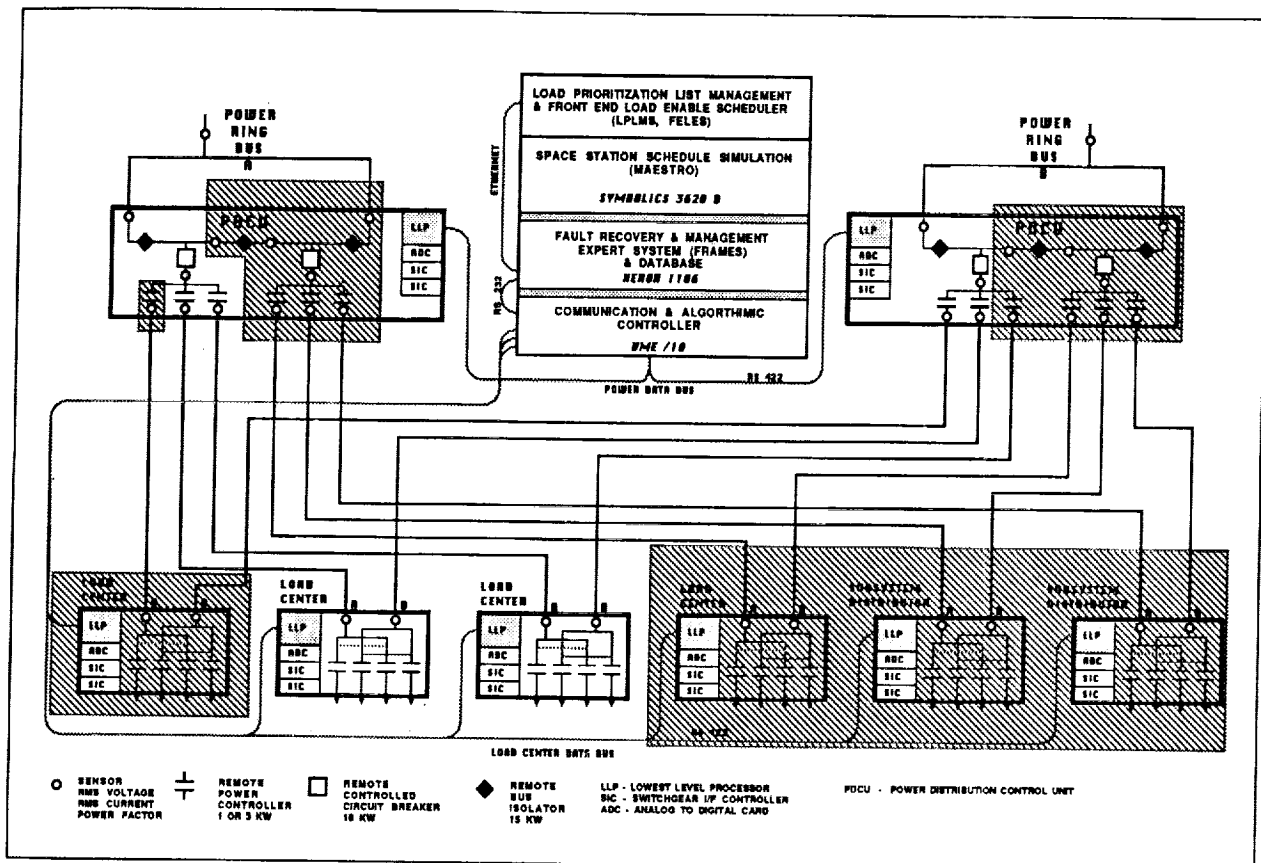


Figure 1 - Current SSM/PMAD Configuration (20 kHz Ring Bus)

Both of the Power Distribution Control Units (PDCU's) contain six 3-kW RPC's, three below each of the RCCB's. The 3-kW RPC's are also used in the Subsystem Distributors while 1-kW RPC's are used in the Load Centers. The 1-kW and 3-kW RPC's differ only in their current ratings and trip levels. The RPC's are similar to, but somewhat more sophisticated than, the RCCB's. In addition to the RCCB capabilities, RPC's also provide current limiting and can trip on under voltages, immediate overcurrents, and ground faults. The same relay symbol is used for both 1-kW and 3-kW RPC's in Figure 1.

Finally, the planned locations of all sensors are represented as white circles in Figure 1. These sensor packages exist throughout the system with each package containing a voltage and current sensor allowing for RMS voltage and current, average power, and power factor calculations. Due to the current values available from the RCCB's and RPC's, the automation software now makes limited use of the sensor readings; thus only a few of the sensors are installed.

#### Software and Platforms

In addition to the power distribution hardware, the system includes computer control through a hierarchy of processes. Each step up the hierarchy shows a decrease in speed (from microseconds at the lowest level, to milliseconds or seconds at

the middle level, to seconds or minutes at the highest level) and an increase in sophistication. The lowest level process consists of fast, simple (from a computing standpoint) switchgear, capable of quickly safing the system. The next level consists of local load center processors called Lowest Level Processors (LLP's). These LLP's execute load scheduling, perform redundant switching, and shed loads which use more than scheduled power. The level above the LLP's contains a CAC which coordinates communications with the highest level. Finally, at the highest level, three cooperating AI systems manage load prioritization, load scheduling, load shedding, and fault recovery and management.

The LLP's are at the level nearest the power hardware and consist of Motorola MVME 107 single-board 68010 based computers, each with an RS422 communications board. Each LLP communicates over RS422 to the power hardware through one or two Switch Interface Cards (SIC's), which in turn communicate with the RPC's and the Analog to Digital Converter Cards for sensor data packets. Each lowest level domain — Load Center, Subsystem Distributor, and PDCU — contains one LLP. Each LLP is responsible for controlling switches and monitoring all of the sensor readings and switch positions in its lowest level domain. The LLP also executes scheduled changes in switch positions, sheds any loads which exceed their scheduled maximum, and switches redundant loads to their secondary bus (in a Load

Center or Subsystem Distributor) if the load's primary source is interrupted.

The LLP notifies the next higher machine in the hierarchy, the CAC, of any anomalies noted. The CAC routes information to the various LLP's, provides the source code which is downloaded to the LLP's when the system is initialized, and serves as the control station when the breadboard is operated in manual mode. Messages pass between the CAC, the LLP's, and either the Fault Recovery and Management Expert System (FRAMES), Maestro, or the Load Priority List Maintenance System (LPLMS). The CAC is resident on a Motorola VME-10 computer and communication is over RS422 to the LLP's and over RS232C to a Xerox 1186 for the others.

FRAMES, Maestro, and the LPLMS share the highest level of the software hierarchy. FRAMES monitors the system for anomalies. Maestro is a resource scheduler which can create a schedule based on multiple constraints. The LPLMS keeps up with the dynamic priorities of all payloads and develops load shedding lists for contingencies which require load shedding. Each of these three systems is described below.

FRAMES is responsible for detecting faults, advising the operator of appropriate corrective actions, and in many cases autonomously implementing corrective actions through power system reconfiguration [2]. FRAMES and the LLP's concurrently receive a schedule from Maestro. Then, FRAMES receives notification of any anomalies, such as tripped breakers or shed loads, from the LLP's. Messages containing sensor readings are also sent to FRAMES. Next, FRAMES uses this information and attempts to find an explanation for any anomalies. If this explanation requires removing some pieces of equipment from service, FRAMES does so and notifies Maestro to adjust the schedule accordingly. Finally, FRAMES shows schematically the results of the anomaly, explains to the user the reasoning behind these results, and waits for notification of further anomalies.

Maestro is a multiple constraint resource scheduler. The constraints currently being used in the SSM/PMAD Breadboard include crew member requirements, equipment resources, and power resources. In this breadboard, power is the resource of most concern. Power is allocated by the amount available to the whole system and by the ability of intervening components to supply the power, e.g., multiple 1-kW RPC's below a single 3-kW RPC [2].

A user selects a number of activities from the activity library and requests that they be scheduled. Then Maestro creates an initial schedule for the system. An activity is made up of a task name, a base priority of the task, the number of times the task should be repeated, and a collection of one or more subtasks. The powered equipment is chosen from the equipment library. The powered equipment description includes how much power it is allowed, whether it may be tested by the system (have power toggled on and off), where it may be connected, and whether it can be redundant. Elements may be added to the Activity or Equipment Libraries by using the appropriate editor. The activities are

scheduled, according to their priority, such that no constraints are violated. From the schedule, 30-minute sections of the complete schedule, called event lists, are created. An event list shows when each switch should be turned on or off, how much current it is allowed to pass, whether it is testable, and whether it can switch to redundant. A new event list is created every 30 minutes, unless some anomaly causes a contingency list to be created within that time. A contingency list includes a new event list and a new Load Priority List which resets the timer.

The third of the AI systems is the LPLMS. The LPLMS uses information from the event list and the activity library, along with its own rules, to dynamically assign relative priority to each active load in the system. The load priority list is used to shed loads in case of power reductions. A new list is sent to the LLP's at least every 15 minutes (less than 15 if a contingency occurs).

#### SYSTEM MODIFICATIONS

Some major changes are planned for the SSM/PMAD Breadboard. Work is now under way to change the system from the current 20 kHz 208 Vac Ring Bus configuration to a 150 Vdc Star Bus configuration. In the automation and control area, there will be a change in the hardware platforms for the LLP's, CAC, and FRAMES, and an upgrade to the communications so that Ethernet can be used throughout. Figure 2 illustrates these modifications. A new Knowledge Based Management System (KBMS) will be introduced into the system, as well as a centralized enhanced model. An intermediate level of autonomy will be added so that "expert help" will be available to the operator. Finally, SSM/PMAD will be connected to Lewis Research Center's Autonomous Power System (LeRC APS).

#### Power Hardware Changes

The change to a 150 Vdc Star Bus topology on the breadboard followed modifications in the Space Station Freedom baseline. As Figure 2 shows, the change is most pronounced in the simplified PDCU's. The change to dc requires replacing all of the switches, except the RBI's, and much of the wiring. Although switching the dc current is more difficult, the logic associated with each switch can be reduced, since there is no need to detect zero crossings or phase angle. In addition, Subsystem Distributors are no longer required and sensors packets will only consist of current and voltage sensors.

The conversion to the Star Bus Topology will remove the requirement for RCCB's. Initially the current RBI's will be used, until a new 25-kW Remote Bus Isolator, capable of switching current, is developed and added to the system. The topology has much more impact on the software than does the dc change. Maestro, FRAMES, and the CAC all use power system topology information in their operations and it is this distribution of similar information which indicates the need for a centralized, enhanced model of the system. Until that model is completed, the code will be modified to keep the current capabilities.

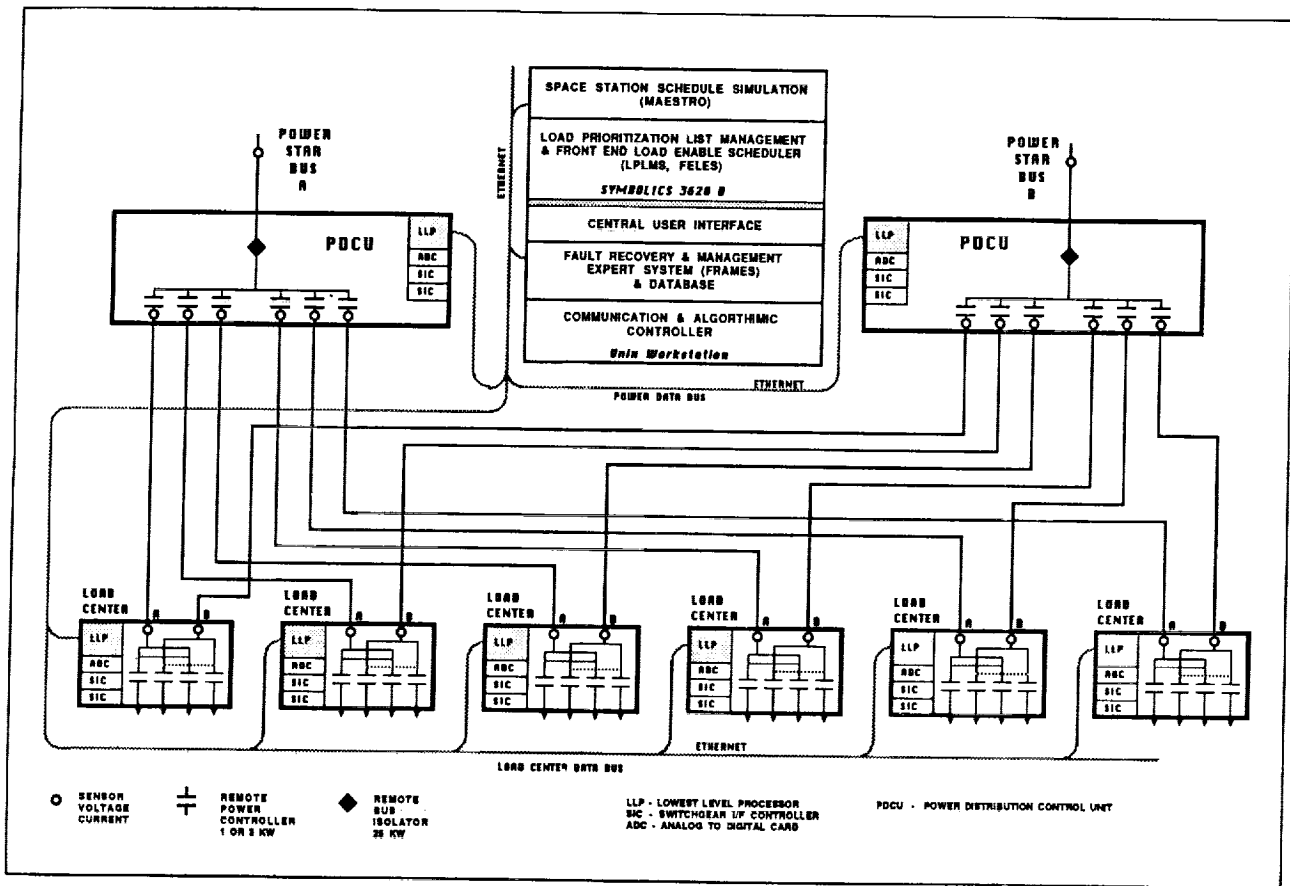


Figure 2 - Planned SSM/PMAD Configuration (dc Star Bus)

#### Automation Hardware Upgrades

Some computer and communications upgrades are in process for the breadboard. The RS232C link between the platforms for FRAMES and the CAC has been a bottleneck. The CAC's inability to communicate with more than one LLP at a time has been an even worse problem. Also, while running FRAMES, the Xerox 1186 Workstation is operating at its limit. It cannot handle the planned improvements and additions to FRAMES. For these reasons, it was decided to replace both the Xerox 1186 and the CAC's platform, a Motorola VME-10, with a single, high power workstation. Today's workstations are very capable in both computing and communicating. A machine comparable to a Sun 4 should be able to host the current CAC and FRAMES functionality with significant resources left over for development of the KBMS and the Enhanced Model. Since the software for the CAC is written in Pascal, and FRAMES is written in Common Lisp using the Common Lisp Object System (both available on most common UNIX based workstations), software porting should be relatively straightforward. An added advantage of the new Workstation is the availability of relatively inexpensive color graphics. A central user interface would be a big plus when operating in manual or semi-manual mode, as well as for monitoring fully autonomous operation.

Combining the CAC and FRAMES on a single platform will remove the RS232C bottleneck while communications to the Symbolics will continue to be via Ethernet. Ideally, communications to the LLP's should also be by Ethernet. The 68010 processors in the current LLP's are capable of supporting their current utility and the addition of Ethernet communications. However, the cost of adding Ethernet boards to the existing VME-bus backbone is higher than getting new 80386 based computers with new rack-mount cabinets, Ethernet boards, floppy disk drives, monitors, and keyboards. Because of lower cost, the vast amount of software available for 80386 machines, and the Space Station Freedom baseline of the 80386 for onboard processing, the decision was made to purchase new 80386 based computers for the LLP's.

#### Other Changes

The KBMS is now under development. The rules in each of the AI systems will be organized into modular groups with the KBMS controlling rule execution and managing modification of the rule bases. In addition, the KBMS will control operation of the user interface.

Working with the KBMS will be the Enhanced Model. This causal model will support a better user interface, provide for more general diagnostic capabilities, serve as a basis for simulated fault

injection and "what if" capabilities, allow for construction of various topologies fairly easily, permit a more natural representation of constraints in the domain of power systems, and enable natural growth of power system fault diagnosis and management. In addition, it could allow easy domain adjustments and upgrading, allow new techniques in reasoning to be used, and would make domain knowledge as it exists in the knowledge base easier to develop and manage.

In the current system, control is either fully autonomous, once the desired activities are chosen and the breadboard started, or fully manual through a rudimentary monochromatic menu system. For the modified system, layers of intermediate autonomy will be developed so that the information contained in the system will be available at the level desired by the user.

Since the SSM/PMAD Breadboard is required to support the development of the Power Management and Distribution system for the space station modules, Boeing Aerospace Company, the prime contractor for Work Package #1 at MSFC, will be the primary user of the system. Therefore, continuing breadboard advanced development will be on a noninterference basis with the Boeing work. Finally, since Lewis Research Center (LeRC) is responsible for the space station power generation, storage, and primary distribution, the SSM/PMAD Breadboard will be interfaced with the LeRC Autonomous Power System Demonstration Program to help ensure that the two will be well integrated on Space Station Freedom.

#### CONCLUSIONS

This paper has presented an overview of the current status of the Space Station Module Power Management and Distribution Breadboard, and a glance at the plans for the future. Testing has demonstrated that, though certainly still a development system, the breadboard is quite mature in its ability to operate autonomously and to correctly react to many power system faults.

The current breadboard is about to undergo major revisions which will permit the system to be even more capable and mature. The change to a dc Star topology brings the breadboard more in line with plans for Space Station Freedom modules. Development of cooperating expert system technology, KBMS, and Enhanced Modeling will keep the breadboard on the leading edge of spacecraft power automation. Continued use by MSFC and Boeing and joint projects with LeRC will all contribute to make the SSM/PMAD Breadboard a valuable resource to MSFC, NASA, and the world.

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